Evaluating Near-Field TH Processes at Yucca Mountain: The Impact of Natural Convection

Jens T. Birkholzer, Nicholaus Halecky, and Bo Bodvarsson
Contact: Jens T. Birkholzer, 510/486-7134, jtbirkholzer@lbl.gov

RESEARCH OBJECTIVES

The heat output of the waste to be emplaced at Yucca Mountain will strongly affect the thermal-hydrological (TH) conditions in and near the geologic repository. Recent analysis of gas flows within emplacement drifts has demonstrated that the open tunnels will act as important conduits for natural convection processes. As a result, water will evaporate from the drift walls in elevated-temperature sections of the drifts, migrate along the drifts, and condense in cooler sections (i.e., the end sections with no emplaced waste). Thus, evaporation driven by natural convection has great potential for reducing the moisture content in the near-drift fractured rock, which in turn would reduce the potential for formation of pore water drops at the drift wall (and subsequent dripping into the opening). However, up to now, natural convection processes have been neglected in predictions of future TH behavior in the fractured porous rock at Yucca Mountain. We have developed a new simulation method that couples existing tools for simulating TH conditions in the fractured formation (Birkholzer et al., 2004) with modules that approximate natural convection and evaporation conditions in heated emplacement drifts.

APPROACH

The new simulation method simultaneously handles (1) the flow and energy transport processes in the fractured rock; (2) the flow and energy transport processes in the open drifts; and (3) the heat and mass exchanges at the interface between the rock formation and the cavity. This integrated modeling approach ensures consistency between the thermal-hydrological conditions in the fractured rock and those in the open drift. In-drift convection and turbulent mixing is approximated with a lumped-parameter approach, following a procedure developed by scientists at Sandia National Laboratories for estimating condensation processes in waste emplacement drifts (BSC, 2004). A lumped-parameter approximation means that the turbulent mixing is not solved in detail, but approximated as a binary diffusion process, with effective diffusion coefficients estimated from supporting computational-fluid-dynamics analyses. The lumped-parameter simulations are conducted with a newly developed version of the multiphase, multicomponent simulator TOUGH2, which includes a new module for in-drift convection.

ACCOMPLISHMENTS

We have successfully applied the new modeling methodology to study future TH conditions in a three-dimensional model domain comprising a representative emplacement drift and the surrounding fractured rock (Figure 1). Sensitivity studies were conducted simulating different degrees of convective mixing within the open tunnels. Our results have shown that natural convection can indeed remove significant amounts of vapor from the heated fractured rock. For cases with relatively strong convective mixing, evaporative conditions will prevail over long stretches of emplacement drifts for several thousand years after emplacement. At early times, vapor is driven from the formation into the drifts by both convective flow (from pressure buildup caused by boiling) and diffusive flow (resulting from vapor concentration gradients). At later times, diffusive flow dominates.

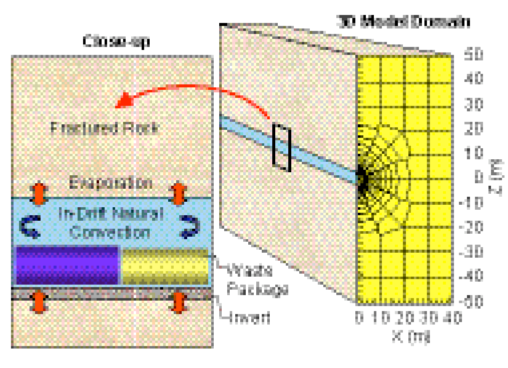

Figure 1. Schematic showing 3-D model domain with emplacement drift and fractured rock

SIGNIFICANCE OF FINDINGS

Compared to previous models that neglect in-drift convection, this new modeling approach predicts TH conditions that are much less favorable for seepage of formation water into emplacement drifts. Application of this method to drift seepage prediction models would significantly reduce the expected seepage rates at Yucca Mountain and thereby improve the predicted performance of the repository. The new model could also be used to assess innovative emplacement designs that deliberately utilize natural convection processes, to generate an in-drift environment beneficial to the performance of natural and engineered barriers (less seepage, less humidity).

RELATED PUBLICATIONS

Birkholzer, J., S. Mukhopadhyay, and Y.M. Tsang, Modeling seepage into heated waste emplacement tunnels in unsaturated fractured rock. Vadose Zone Journal, 3, 819–836, 2004. Berkeley Lab Report LBNL-53894.

Bechtel SAIC Company, In-drift natural convection and condensation. Yucca Mountain Project Report, MDL-EBS-MD-000001 REV 00, Bechtel SAIC Company, Las Vegas, NV, 2004.

ACKNOWLEDGMENTS

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